

# Resonance interpretation of the bump structure in the $\gamma p \rightarrow K^+ \Lambda(1520)$ differential cross section

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## Abstract.

We investigate the  $\Lambda(1520)$  photoproduction in the  $\bar{\gamma}p \rightarrow K^+ \Lambda(1520)$  reaction within the effective Lagrangian method near threshold. In addition to the "background" contributions from the contact,  $t$ -channel  $K$  exchange, and  $s$ -channel nucleon pole terms, which were already considered in previous works, the contribution from the nucleon resonance  $N^*(2080)$  (spin-parity  $J^P = 3/2^-$ ) is also considered. We show that the inclusion of the nucleon resonance  $N^*(2080)$  leads to a fairly good description of the new LEPS differential cross-section data, and that these measurements can be used to determine some of the properties of this latter resonance.

**Keywords:**  $N^*(2080)$  resonance, bump structure, photoproduction

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## INTRODUCTION

The  $\Lambda(1520)$  ( $\equiv \Lambda^*$ ) photoproduction in the  $\gamma p \rightarrow K^+ \Lambda^*$  reaction is an interesting tool to gain a deeper understanding of the interaction among strange hadrons and also on the nature of baryon resonances. Recently, this reaction has been examined at photon energies below 2.4 GeV in the SPring-8 LEPS experiment [1]. For an invariant  $\gamma p$  mass  $W \simeq 2.11$  GeV, the experiment has reported a new bump structure in the differential cross section at forward  $K^+$  angles, which might hint to a sizeable contribution from nucleon resonances in the  $s$ -channel.

Different dominant mechanisms [2, 3, 4] have been proposed to describe the high-energy results from LAMP2 [5]. However, all these models fail to describe the forward bump structure in the new LEPS data. Thus, we reanalyze the  $\bar{\gamma}p \rightarrow K^+ \Lambda^*$  reaction within the effective Lagrangian method. In addition to the "background" contributions from the contact,  $t$ -channel  $K$  exchange, and  $s$ -channel nucleon pole terms, which were already considered in previous works, we have also studied possible contributions from nucleon resonances. Unfortunately, the information about nucleon resonances in the relevant energy region ( $\sim 2.1$ ) GeV is scarce [6], and we should rely on theoretical schemes, such that of Ref. [7] based in a quark model (QM) description of hadrons. Among the possible nucleon resonances, we have finally considered only the two-star  $D$ -wave  $J^P = 3/2^-$   $N^*(2080)$  ( $\equiv N^*$ ) one. Although the  $N^*(2080)$  resonance is listed in the Particle Data Group (PDG) book, the evidence of its existence is poor or only fair and further work is required to verify its existence and to determine its properties. In this respect, we show here how the recent LEPS measurements could be used to determine

some of the properties of this resonance.

## FORMALISM

The basic tree level Feynman diagrams for the  $\vec{\gamma}p \rightarrow K^+\Lambda^*$  reaction are depicted in the Fig. 1. To compute the contributions of each of these terms, we use the interaction Lagrangian densities of Refs. [3, 4],

$$\mathcal{L}_{\gamma KK} = -ie(K^-\partial^\mu K^+ - K^+\partial^\mu K^-)A_\mu, \quad (1)$$

$$\mathcal{L}_{Kp\Lambda^*} = \frac{g_{KN\Lambda^*}}{m_K} \bar{\Lambda}^{*\mu} (\partial_\mu K^-) \gamma_5 p + \text{h.c.}, \quad (2)$$

$$\mathcal{L}_{\gamma pp} = -e\bar{p} \left( A - \frac{\kappa_p}{2M_N} \sigma_{\mu\nu} (\partial^\nu A^\mu) \right) p + \text{h.c.}, \quad (3)$$

$$\mathcal{L}_{\gamma Kp\Lambda^*} = -ie \frac{g_{KN\Lambda^*}}{m_K} \bar{\Lambda}^{*\mu} A_\mu K^- \gamma_5 p + \text{h.c.}, \quad (4)$$

$$\mathcal{L}_{\gamma NN^*} = \frac{ief_1}{2m_N} \bar{N}_\mu^* \gamma_\nu F^{\mu\nu} N - \frac{ef_2}{(2m_N)^2} \bar{N}_\mu^* F^{\mu\nu} \partial_\nu N + \text{h.c.}, \quad (5)$$

$$\mathcal{L}_{K\Lambda^*N^*} = \frac{g_1}{m_K} \bar{\Lambda}_\mu^* \gamma_5 \gamma_\alpha (\partial^\alpha K) N^{*\mu} + \frac{ig_2}{m_K^2} \bar{\Lambda}_\mu^* \gamma_5 (\partial^\mu \partial_\nu K) N^{*\nu} + \text{h.c.}, \quad (6)$$

where  $e = \sqrt{4\pi\alpha} > 0$  ( $\alpha = 1/137.036$  is the fine-structure constant),  $\kappa_p = 1.79$ ,  $A_\mu$  and  $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$  are the proton charge and magnetic moment, and the photon field and electromagnetic field tensor, respectively.

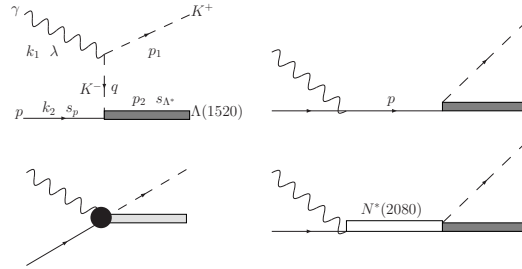


FIGURE 1. Model for the  $\gamma p \rightarrow \Lambda^* K^+$  reaction.

With the effective interaction Lagrangian densities given above, we can easily construct the invariant scattering amplitudes (see Ref. [8] for its detailed expression). Moreover, we also include the form factors, respecting gauge invariance as follows

$$f_i = \frac{\Lambda_i^4}{\Lambda_i^4 + (q_i^2 - M_i^2)^2}, \quad i = s, t, R \quad (7)$$

$$f_c = f_s + f_t - f_s f_t, \quad \text{and} \quad \begin{cases} q_s^2 = q_R^2 = s, q_t^2 = q^2, \\ M_s = M_N, \\ M_R = M_{N^*}, \\ M_t = m_K. \end{cases} \quad (8)$$

We will consider different cut-off values for the background and resonant terms, i.e.  $\Lambda_s = \Lambda_t \neq \Lambda_R$ .

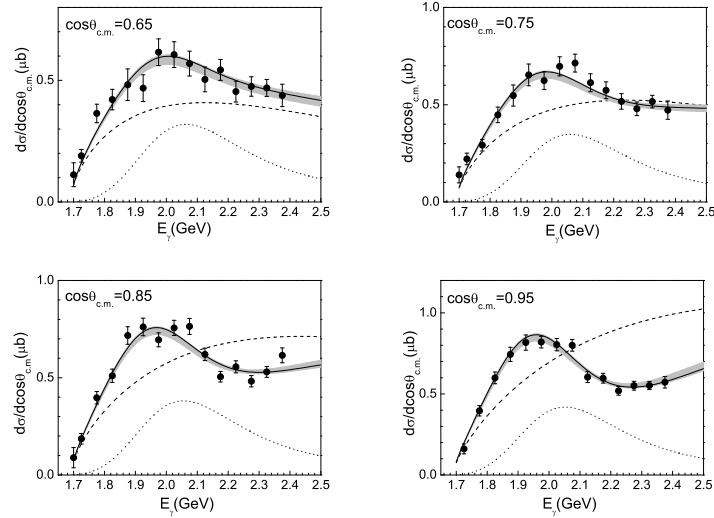
## NUMERICAL RESULTS AND DISCUSSION

The differential cross section, in the center of mass frame (C.M.), and for a polarized photon beam reads,

$$\left. \frac{d\sigma}{d\Omega} \right|_{\text{C.M.}} = \frac{|\vec{k}_1^{\text{C.M.}}| |\vec{p}_1^{\text{C.M.}}|}{4\pi^2} \frac{M_N M_{\Lambda^*}}{(s - M_N^2)^2} \left( \frac{1}{2} \sum_{s_p, s_{\Lambda^*}} |T|^2 \right) \quad (9)$$

where  $\vec{k}_1^{\text{C.M.}}$  and  $\vec{p}_1^{\text{C.M.}}$  are the photon and  $K^+$  meson c.m. three-momenta.

We perform eight parameter ( $ef_1, ef_2, g_1, g_2, \Lambda_s = \Lambda_t, \Lambda_R, M_{N^*}$  and  $\Gamma_{N^*}$ )  $\chi^2$ -fits to the LEPS  $d\sigma/d(\cos \theta_{\text{C.M.}})$  data at forward angles. There is a total of 59 data points. These data correspond to forward  $K^+$  angles and are given for four intervals of  $\cos \theta_{\text{C.M.}}$  ranging from 1 down to 0.6. To compute the cross sections in each interval we always use the corresponding mean value of  $\cos \theta_{\text{C.M.}}$ . The fitted parameters are  $ef_1 = 0.177 \pm 0.023$ ,  $ef_2 = -0.082 \pm 0.023$ ,  $g_1 = 1.4 \pm 0.3$ ,  $g_2 = 5.5 \pm 1.8$ ,  $\Lambda_s = \Lambda_t = 604 \pm 2$  (MeV),  $\Lambda_R = 909 \pm 55$  (MeV),  $M_{N^*} = 2115 \pm 8$  (MeV), and  $\Gamma_{N^*} = 254 \pm 24$  (MeV). We show the results in Figure 2.



**FIGURE 2.**  $\gamma p \rightarrow K^+ \Lambda^*$  differential  $d\sigma/d(\cos \theta_{\text{C.M.}})$  cross sections compared with the LEPS data [1]. Dashed and dotted lines show the contributions from the background and  $N^*$  resonance terms, respectively, while the solid line displays the full result. For this latter curve we also show the statistical 68% CL band.

With the strong coupling constants obtained from the  $\chi^2$  fits, we can evaluate the branching fraction of the  $N^*(2080)$  decay into the  $\Lambda^* K$  channel, which turns out to be  $7.5\% \pm 2.8\%$ . We find that the  $\Lambda^* K$  mode is quite important. This large coupling supports the findings of the QM approach [7].

## SUMMARY AND CONCLUSIONS

We have studied the  $\gamma p \rightarrow \Lambda^* K^+$  reaction at low energies within a effective Lagrangian approach. In particular, we have paid an special attention to a bump structure in the differential cross section at forward  $K^+$  angles reported in the recent SPring-8 LEPS experiment [1]. Starting from the background contributions studied in previous works, we have shown that this bump might be described thanks to the inclusion of the nucleon resonance  $N^*(2080)$ . We have fitted its mass, width and hadronic  $\Lambda^* K^+$  and electromagnetic  $N^* N \gamma$  couplings to data. We have found that this resonance would have a large decay width into  $\Lambda^* K$ , which is compatible with the findings of the QM approach [7].

Other explanations of the observed bump in the SPring-8 LEPS data are also possible. Indeed, in the very same experimental paper (Ref. [1]) where the data is published, it is suggested that this structure might be due to a  $J^P = \frac{3}{2}^+$  nucleon resonance, with a mass of 2.11 GeV and a width of 140 MeV. However, a nucleon resonance with these features is not listed in the PDG book [6]. In Ref. [1], it is also mentioned the possibility of a sizeable contribution from a higher ( $J^P = \frac{5}{2}^-$ ) baryon state and/or the existence of a new reaction process, for instance, an interference with  $\phi$  photo-production [9, 10].

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